NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

ARPA Order No. 44-61
Advanced Research Projects Agency
Office of the Secretary of Defense

EXPLOSIVES RESEARCH LABORATORY

STUDIES ON DEFLAGRATION TO DETONATION IN PROPELLANTS AND EXPLOSIVES

Quarterly Report

July 1, 1961 to September 30, 1961

62-1-3
NOX

BUREAU OF MINES, PITTSBURGH, PA.

UNITED STATES
DEPARTMENT OF
THE INTERIOR

STUDIES ON DEFLAGRATION TO DETONATION

IN PROPELLANTS AND EXPLOSIVES

Quarterly Report

July 1, 1961 to September 30, 1961

Prepared for:

Advanced Research Projects Agency
Office of the Secretary of Defense
ARPA Order No. 44-61

by

F. C. Gibson
C. R. Summers
F. H. Scott

Approved by:

Robert W. Van Dolah

Robert W. Van Dolah
Chief, Explosives Research Laboratory

U. S. Department of the Interior
Bureau of Mines
Pittsburgh, Pa.
October 30, 1961

STUDIES ON DEFLAGRATION TO DETONATION
IN PROPELLANTS AND EXPLOSIVES

INTRODUCTION

Methods for the evaluation of sensitivity to detonation of propellants and explosives continue to be of paramount importance. Many empirical tests have been devised and applied to such studies only to recognize, at a later date, ambiguities inherent to the test. Furthermore, propellant preparation processes sometimes malfunction during the mixing process prior to casting and curing. It is our intention to attempt, on a laboratory scale, to simulate environmental conditions that are likely to cause such misbehaviors and malfunctions.

Since many current propellant formulations use double-base systems, the basic nitroglycerin ingredient serves well as a material on which studies can be made. It is particularly useful for photographic study because of its transparency. However, since solid propellants and explosives are opaque, evaluation of burning and detonation behavior must be made by means of electrical and/or modified optical methods.

We are developing an optical technique for sensing behavior within an opaque body that appears promising for use in combustion rate studies when correlated with the results from the application of the resistance element and pressure probe techniques.

Refinement of the latter has been made where the application of this technique to burning rate, detonation rate, and critical diameter studies on advanced formulations are contemplated in a cooperative arrangement with one or more of the ARPA major propellant development contractors. Methods employed are applicable to relatively small quantities of material for a given test. Arrangements have been made with American Cyanamid, Stamford, Connecticut, and collaboration with other companies is contemplated pending preliminary evaluation of the technique on a single company's product; however, if laboratory samples cannot be transported to our facility, useful instrumentation methods can be suggested or, in part, provided.

In an earlier report of this series[1/], the influence of externally applied electric and magnetic fields on detonation had been discussed. With our new photographic facilities, i.e., the streak camera and the .050 μsec. Kerr Cell Camera, research into this facet of detonation is facilitated. The high-speed Cordin Framing Camera, which is now scheduled for delivery in the last quarter of 1961, and a two-channel micro-flash X-ray camera will become available to supplement the instrumentation now on hand.

General observations pertaining to detonation phenomena are reported when they appear pertinent to a better understanding of detonation events or when a useful device, developed as a sidelight, results from the work.

EXPERIMENTAL

A. Streak photographic study of effects of electric fields on detonation

An investigation into the effect of externally applied electric fields during both the growth and steady-state stages of detona-

1/ Bureau of Mines Quarterly Report, "Studies on Deflagration to Detonation in Propellants and Explosives", Office of the Secretary of Defense, ARPA Order No. 44-61, January 1, 1961 to March 30, 1961.

tion was begun. Based on earlier work in this field, the Cordin streak camera was used to determine the effect on propagation of detonation by (1) electrodes placed in explosive charges of both high and low density, and (2) an axial electric field during transit of the detonation wave through negative to positive and positive to negative potential gradients.

It had been shown in a recent report[2/] of this series that before the hydrodynamic detonation velocity is attained, a substantial delay time and distance can be introduced by the use of an inert rubber barrier between a donor charge and a low density explosive (about 1.0 g/cm^3) acceptor charge. This behavior was detected by use of the resistance element and also the pressure probe techniques for the continuous measurement of ionization and compression front positions. Since the study of the influence of an electric field on detonation growth precludes the use of electric detection devices, due to stray potentials produced by the high potential field gradients, it was necessary to use optical methods for this investigation. In order to confirm that the delay measured by the electrical method was real, a similar charge configuration was used and the reaction photographed with the streak camera. The charge and the record produced are shown in figure 1. Here a delay distance from the barrier acceptor interface of 35 mm. is shown. The terminal velocity is the anticipated 5.3 mm/μsec. and the supervelocity at the transition point of 6.1 mm/μsec. is doubtless due to an axial initiation with the extra high pseudo-velocity caused by the radial component of the propagation.

Since the growth-to-detonation transition zone is well defined, the position for placement of an electrode system was evident. Shown

2/ See figure 5 referred to in report for January 1 to March 31, 1961 in footnote 1.

in figure 2 is the effect of thin brass electrodes placed at a position on the charge bridging the position of the anticipated transition to high-order detonation. However, no potential was applied to the electrode system. The photographic streak record shows that the presence of the electrodes without an applied potential does influence the propagation to a limited extent and the expected terminal velocity was not quite attained.

When a negative-to-positive field gradient of 20 kv/cm. was applied to the electrodes, the propagation velocity was increased both during passage between the electrodes and more markedly after passing into the downstream end beyond the second electrode; this is apparent when figure 3 is compared with figure 2. However, when the reverse polarity was used, an effect resulted similar to that in which no voltage was applied and is indicated by comparison of figure 4 with figure 2.

If the initiation to detonation is to be influenced by electric fields, it would appear that this influence is stronger during the growth phase and in the lower density explosives. When a higher density (1.62 g/cm^3) charge was employed and direct initiation was used, the presence of the negative-to-positive field had no measurable influence as shown in figure 5.

All of the foregoing tests were made in transparent vessels and the propagation was sensed on the periphery of the charge; it is planned to repeat pertinent tests of this series with the diametric glass wafer system to observe the performance within the charge. A basic experiment was made to show the transitional behavior of a high-order detonation as it progresses across high to low and low to high density segments in the same charge using the wafer system. Figure 6(a) shows the configuration and 6(b) the record obtained. A velocity overshoot is indicated in transition from high to low density with no delay indicated for the low to high density detonation wave transit.

B. Simple plane wave generator

In all of our work where 3/4" diameter donors are used, a simple plane wave generator has resulted from the use of conventional explosive components. Two pressed pellets are stacked to form a booster, as shown in figure 7(a), where the ℓ/d ratio is considerably less than the 3.5:1 recommended for minimum off-end wave front curvature. The effectiveness of the system is doubtless due to peripheral initiation at the detonator-explosive cup wall rather than at the end. A line drawing of the off-end wave front that is produced is shown below the drawing and can be compared to the wave front from a typical card-gap donor (figure 7(b)) which obviously is caused by point initiation. A No. 6 American detonator is used and activated with a capacitive discharge. The photographic streak record is shown in figure 7(c).

C. Procedures to be used in the casting of propellant strands

Special moulds have been prepared for use of the American Cyanamid Company in casting a propellant formulation for our preliminary study. Photographs of the components are shown in figure 8(a). Two banks of three moulds each were designed and constructed for use in burning rate and detonability evaluations of advanced propellant formulations. Conical polyethylene liners were wrapped on a mandrel and inserted into a heated mould; the unit heated to 350°F to fuse the seam of the plastic insert. A resistance element was positioned axially through the apex and held in place by the use of the special jig. The bank of mould forms is shown in figure 8(b); it can be preheated and passed remotely in assembly line fashion under a filling spout from the mixer. This strand configuration has merit in that a minimum quantity of material is required for each strand and several tests, using the resistance element technique, can be conducted with this simple configuration. Among the tests that can be conducted are: (1) burning at ambient and elevated pressures, (2) sensitivity to initiation by direct and attenuated shock waves generated by high explosives boosters, (3) the detonation velocity, and (4) a measure of the critical diameter for sustaining detonation. Additionally, methods for uniform surface initiation by chemical and electrical means can be devised.

The effects of cavitation on the initiation of a detonation-like reaction has been re-emphasized in a recent incident at the Hercules Powder Company, Magna, Utah, involving the vacuum mixing of a high-performance double-base composite solid propellant. The previous report[3/] in this series made reference to cavitation in liquid explosives as a locus of initiation to detonation. Furthermore, the expansion of the bubbles has been considered a possible cause for initiation.

A small-scale transparent replica of a propellant mixer is being designed in which agitation and evacuation is similar to that used in the larger scale mixing. It is planned to conduct a series of photographic tests using such a method to determine if cavitation and evacuation are capable of causing initiation of the propellant

3/ Bureau of Mines Quarterly Report, "Studies on Deflagration to Detonation in Propellants and Explosives", Office of the Secretary of Defense, ARPA Order No. 44-61, April 1, 1961 to June 30, 1961.

slurry, the mechanism involved, and what measures can be taken to minimize the potential explosion hazard.

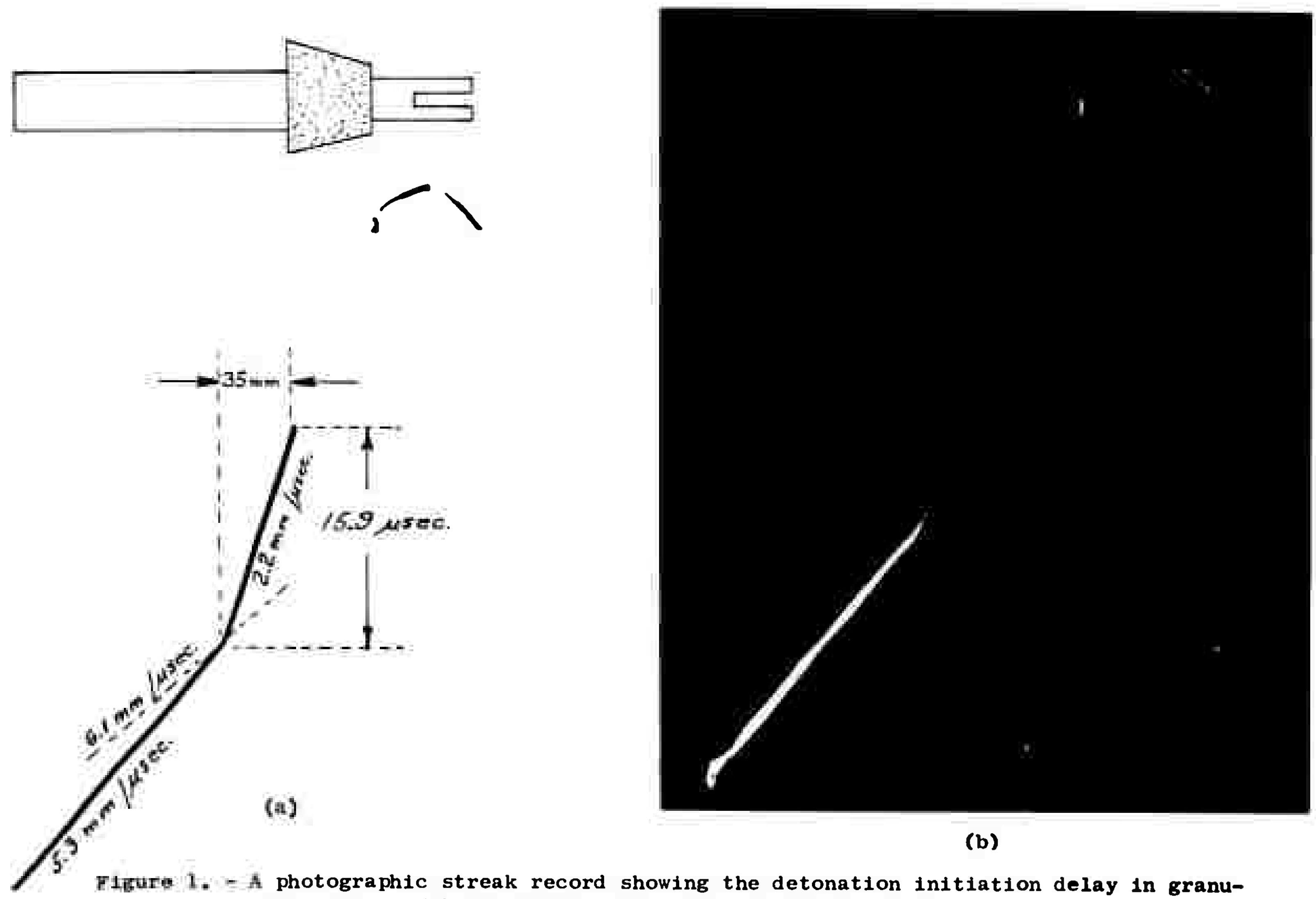
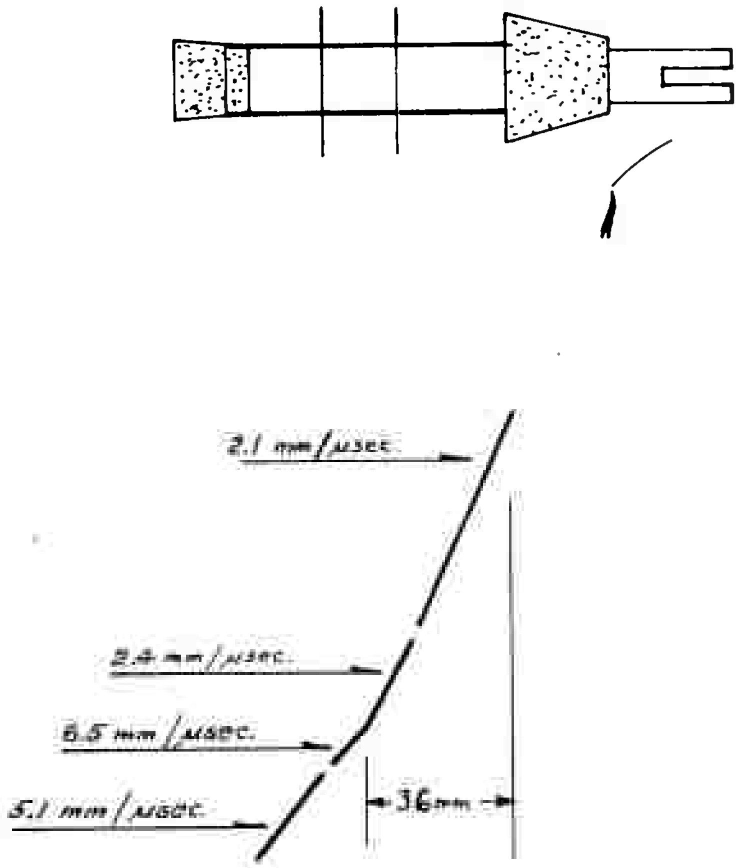
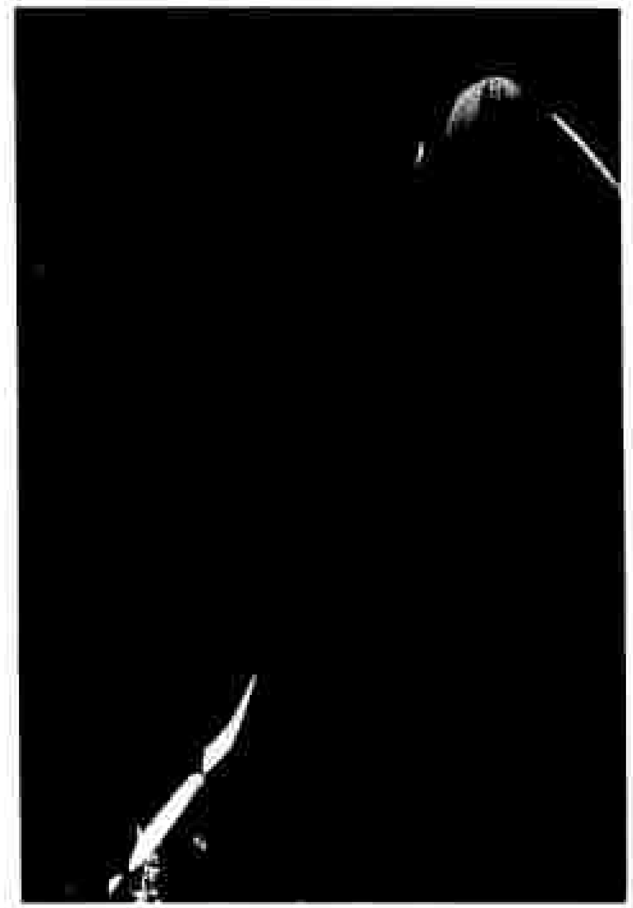


Figure 1. - A photographic streak record showing the detonation initiation delay in granular tetryl: (a) the charge configuration where the shock from an explosive donor is attenuated by an inert rubber barrier and a drawing of the delay and velocities produced; (b) the photographic streak record where the image velocity was 3 mm/μsec. and the object image reduction 2.18 to 1.0.

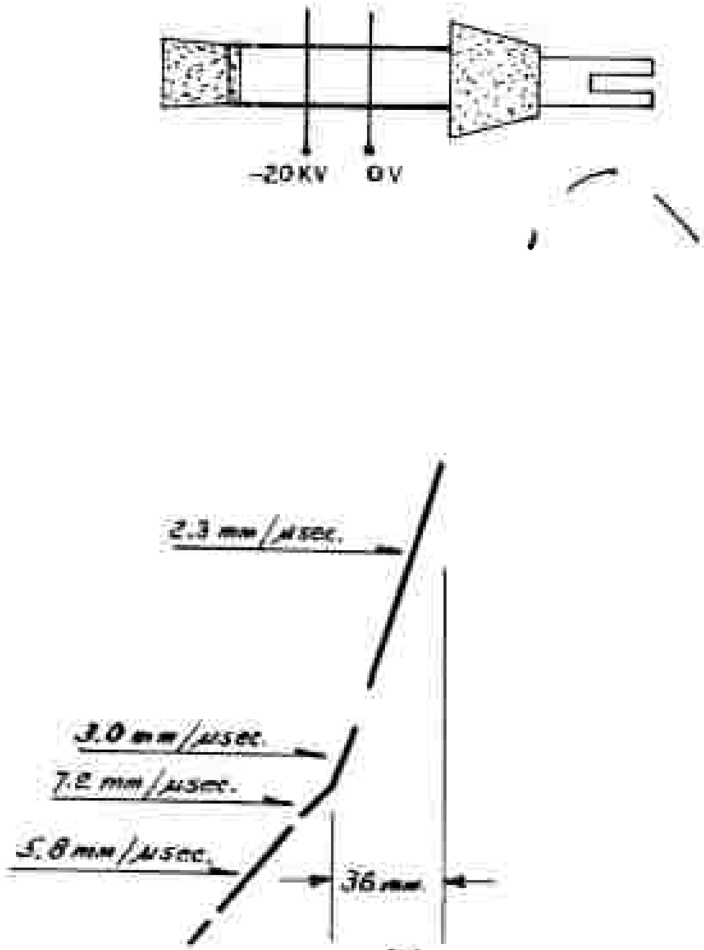


(a)



(b)

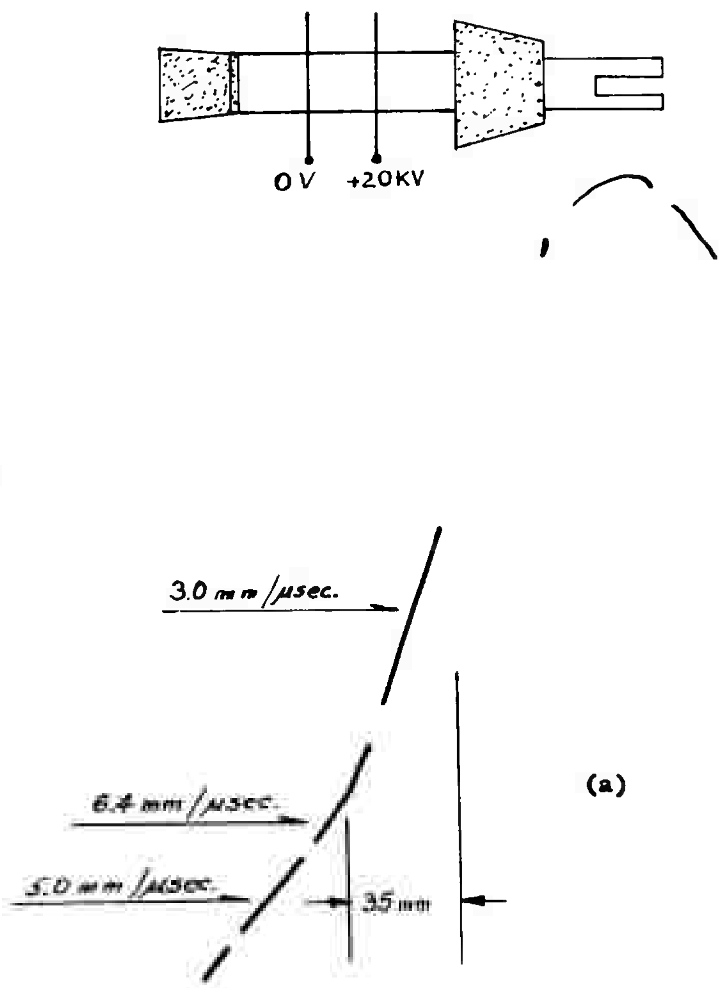
Figure 2. - Influence of the presence of transverse plate electrodes (brass shim stock 0.010" thick) on the propagation velocity of a detonation wave in granular tetryl (density about 1.0 g/cm^3): (a) the charge configuration and resulting velocity record and (b) the actual streak photograph obtained. The image velocity was 3 mm/µsec. and the object-image size reduction is 2.31 to 1.0.



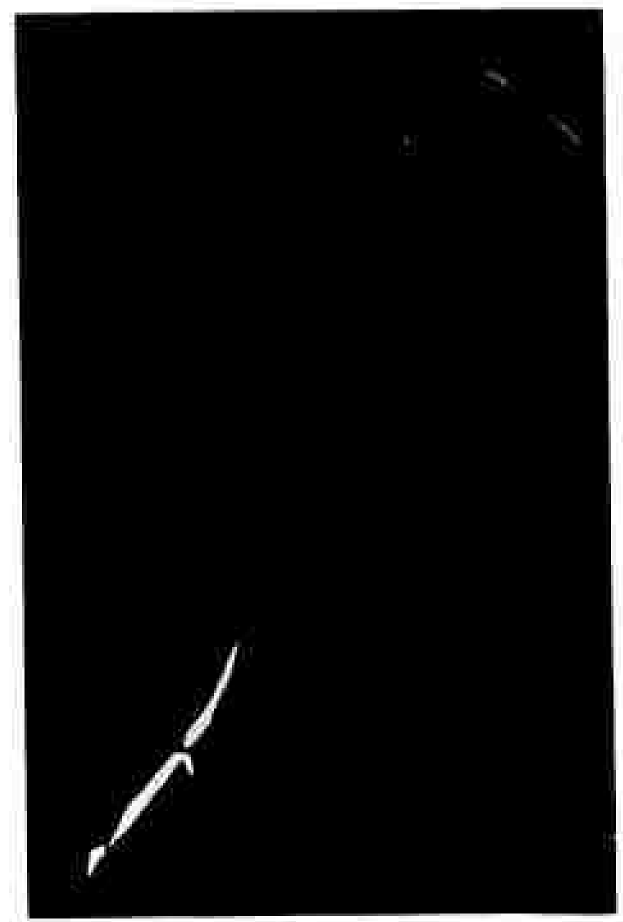
(a)

(b)

Figure 3. - The effect of passing the detonation wave through a region on the charge where a negative-to-positive electric field had been applied: (a) the charge configuration and resulting velocity record where an increased detonation velocity is indicated and (b) the actual streak photograph obtained. The image velocity was 3 mm/μsec. and the object-image size reduction is 2.38 to 1.0.

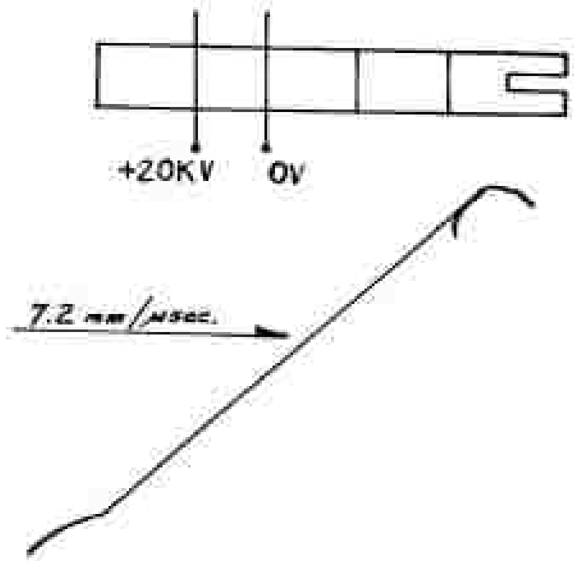


(a)



(b)

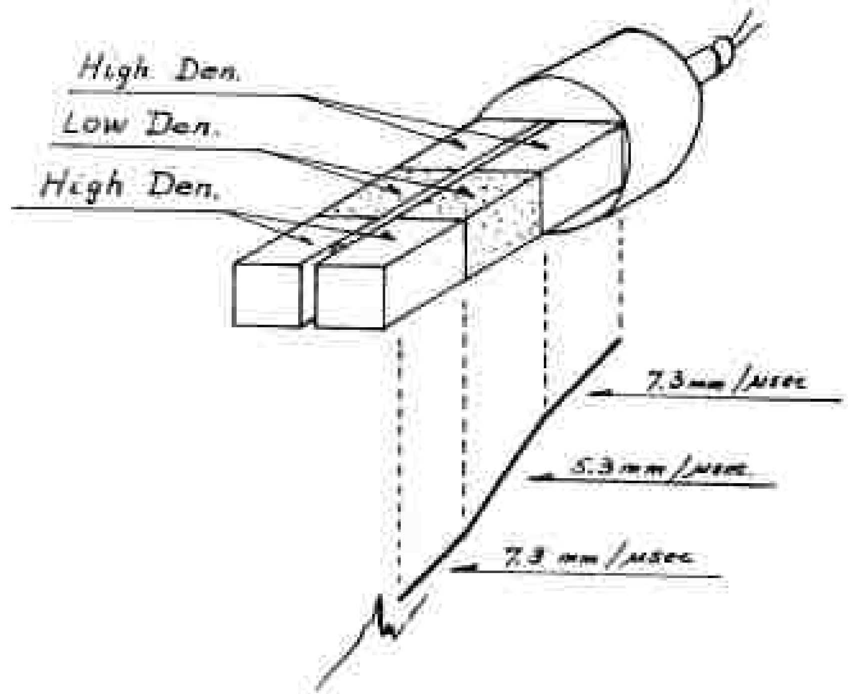
Figure 4. - A test identical to that shown in figure 3 except that a reversed potential was applied to the electrodes: (a) the charge configuration and resulting velocity record where a lower terminal velocity is indicated and (b) the actual streak photograph. The image velocity was 3 mm/μsec. and the object-image size reduction is 2.11 to 1.0.



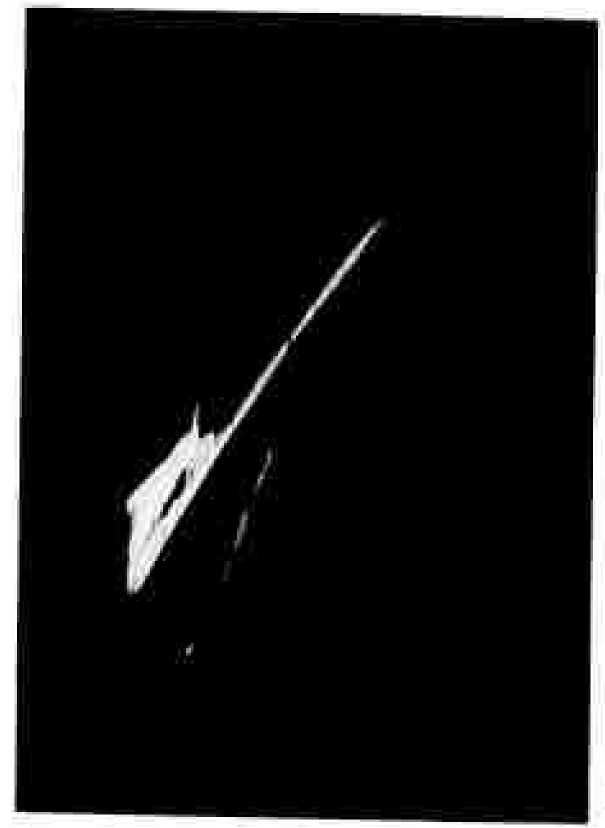
(a)

(b)

Figure 5. - No influence by the application of an electric field to the steady-state detonation in a high density charge (density 1.62 g/cm^3) is indicated: (a) the charge configuration and resulting velocity record and (b) the actual streak photograph obtained. The image velocity was 3 mm/μsec. and the object-image size reduction is 2.25 to 1.0.



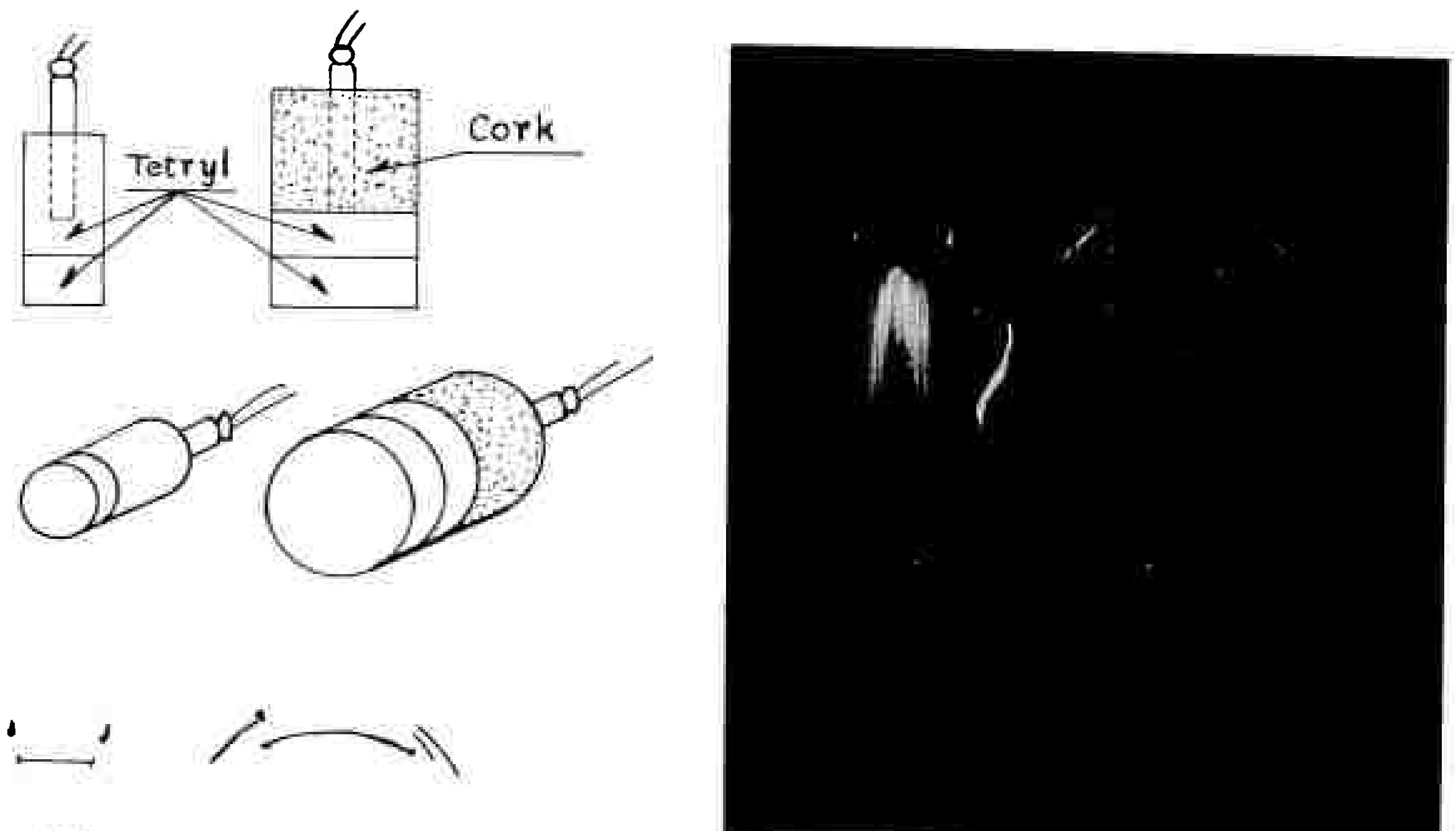
(a)



(b)

Figure 6 (a). - The charge configuration demonstrating the use of a glass wafer to transmit the visible radiation that emanates from within the charge. The transition from a high density to a low density is shown where an overshoot is indicated for the first interface but no delay is encountered at the second interface. Densities of the charge segments are 1.62 g/cm^3 and 0.95 g/cm^3.

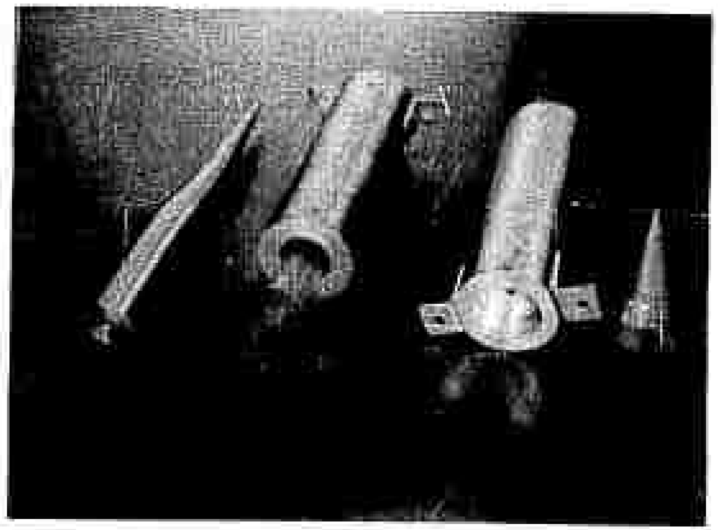
(b). - This is the actual streak record produced. The image velocity was 3 mm/μsec. and the object-image size reduction is 2.63 to 1.0.



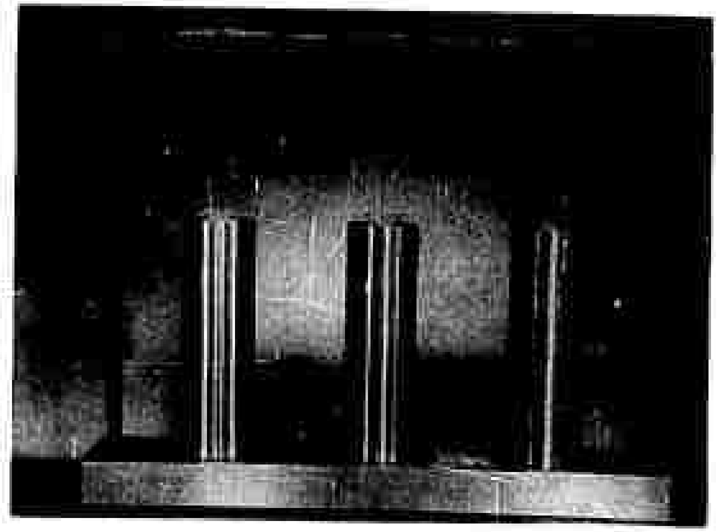
(a) (b) (c)

Figure 7. - End-on streak photographs showing the wave form of the emerging front from two booster configurations.

(a) A cup pellet initiator, (b) the standard card-gap initiator, and (c) the actual photographs of the streak records obtained simultaneously for (a) and (b). The image velocity was 3 mm/μsec. and the object-image size reduction is 2.05 to 1.0.



(a)



(b)

Figure 8. - Components and casting assembly for preparation of conical propellant strands.

(a) Left to right: the mandrel on which the polyethelene liner is wrapped; the liner partially withdrawn from the casting mould; bottom view of this mould showing recess for resistance element lead and for venting and leakage; and the polyethelene liner.

(b) Assembly for production of conical strands showing resistance elements in position for casting.

This report is distributed in accordance with

Joint Army-Navy-Air Force Mailing List

for the distribution of

Solid Propellant Technical Information

dated June 1961

and subsequent changes.

Interior, BuMines, Pittsburgh, Pa.

UNCLASSIF

UNCLASSIF